EXECUTIVE SUMMARY FOR OCCUPANT BEHAVIOR, EGRESS, AND EMERGENCY COMMUNICATIONS

E.1 OVERVIEW

While most attention has properly focused on the nearly three thousand people who lost their lives at the World Trade Center (WTC) site on September 11, 2001, five times that many people successfully evacuated from the WTC towers due to heroic efforts of occupants, as well as emergency responders. Understanding why many, yet not all, survived the WTC attacks was one of the four objectives of the federal building and fire safety investigation of the WTC disaster led by the National Institute of Standards and Technology (NIST).

Success in evacuating a building in an emergency can be characterized by two quantities: the time people needed to evacuate and the time available for them to do so. To the extent the first time exceeded the second, it follows that there will be casualties. When the second time exceeds the first, perhaps by some suitable margin, nearly all should be able to evacuate the building.

For the WTC towers, the times available for escape were cataclysmically established by the collapses of the buildings. Those times were not known in advance by the building occupants or the responders. The times were also considerably shorter, by a factor of three or four, than the time needed to clear the tenant spaces of WTC 1 following the 1993 bombing and an additional factor of two shorter than the time needed to clear the last person from the elevators in the building. Further, some occupants would have been unable to evacuate the buildings given any amount of time due to injuries, entrapment, and/or toxic exposure.

NIST examined the design of the building, the behavior of the people, and the evacuation process in detail to ascertain the factors that factored prominently in the time needed for evacuation.

In order to accomplish this objective, numerous sources of data were collected and analyzed, including: over 1,000 new interviews with survivors; a collection of over 700 published interviews with WTC survivors; 9-1-1 emergency calls; transcripts of emergency communication among building personnel and emergency responders; historical building design drawings, memoranda, and calculations; building modifications and upgrades; formal complaints filed with Occupational Safety and Health Administration; and other relevant material.

There were three forms of interviews with survivors: 803 telephone interviews, over 225 face-to-face interviews, and 6 focus groups. The telephone interviewees were randomly selected using independent proportionate stratification from a list of occupants who had badges to enter WTC 1 or WTC 2 on September 11, 2001. In other words, each occupant of a particular tower had an equal probability of being selected. Roughly 400 occupants in each tower were interviewed in order to achieve a high level of statistical precision within each tower. Reported percentages from tower-specific survey data (n=400) exhibited sampling errors no greater than 2.5 percentage points, and 95 percent confidence intervals of percentages are no greater than ± 5 percentage points. This level of precision was more than adequate for examining characteristics of occupants and egress attributes. With telephone interview results, primary

statistical analyses were in the form of tabulations and linear statistics (e.g., reporting of percentages and average/means). The telephone interview results enabled a scientific projection of the population and distribution of occupants in WTC 1 and WTC 2, as well as causal modeling and multivariate regression analysis to explore fundamental egress issues such as sources of evacuation delay.

The objective of the face-to-face interviews was to gather first-hand accounts and observations of the activities and events inside the buildings on the morning of September 11. This approach identified unknown information, aided in the evaluation of technical hypotheses, and explored motivations for occupant behaviors, while allowing for comparisons to the telephone interview data. There was no recording of the face-to-face interviews, other than random selections, with consent of respondents, for quality control purposes. A typical face-to-face interview averaged approximately two hours. The methodology for the face-to-face interviews was a synthesis of two established methodologies, designed to assist survivors in providing comprehensive and accurate accounts of their evacuation, given the latency between experience and interview. Some groups of occupants were specifically sought in order to explore targeted unknowns. These included occupants near the floors of impact, witnesses to fireballs, mobility-challenged occupants, floor wardens, building personnel with emergency response responsibilities, family members who spoke to an occupant after 8:46:30 a.m., and occupants from regions of the building not addressed by other groups in order to ensure adequate interview coverage for all areas of both towers.

Six focus groups were conducted in order to elicit accurate group representations of specific events or themes and complement the findings of the telephone and face-to-face interviews. The focus groups and the corresponding objectives were:

1. Occupants located near the floors of impact: to explore the extent of the building damage and how the damage influenced the evacuation process.

2. Floor wardens: to explore the implementation of the floor warden procedures and the effect those actions had on the evacuation of the occupants on a floor and the evacuation of the floor warden.

3. Mobility-challenged occupants: to explore the effect of a disability on the evacuation of the occupant and any other individuals who may have assisted or otherwise been affected by the evacuee.

4. Persons with building responsibilities: to capture the unique perspective of non-traditional occupants, including custodians, security, maintenance, or other building staff.

5. Randomly selected evacuees in WTC 1: to further explore the variables from the causal modeling which best explained evacuation delay and normalized stairwell evacuation time, including environmental cues, floor, and activities.

6. Randomly selected evacuees in WTC 2: to further explore variables used in the causal modeling that best explained evacuation delay, including environmental cues, floor, risk perception, and use of elevators.

NIST documented the WTC egress system, including the location of the three primary stairwells, exit doors, core hallways, transfer corridors, wall construction, location and layout of the 100+ elevators in each tower, and emergency communication devices. The design of the egress system was compared to building code requirements of the New York City Building Code, National Fire Protection Association 101 (Life Safety Code), and International Building Code.

NIST documented the emergency procedures, both as they were planned to be carried out, as well as how they were actually implemented on September 11, 2001. The procedures included responsibilities for tenant safety through the floor warden system; pre-planned content of public address system announcements (which varied from public address system announcements made on September 11, 2001); responsibilities of the fire safety director, deputy fire safety director, building security, and supervisors of various contractors (including mechanical, vertical transportation, and electrical). Additionally, interaction among responding agencies such as the Port Authority of New York and New Jersey, the Port Authority Police Department, the New York City Police Department (NYPD), the New York City Fire Department, and contract security were documented.

NIST estimates that there were 8,900 ± 750 people in WTC 1 at 8:46:30 a.m. on September 11, 2001. Similarly, NIST estimates that there were 8,540 ± 920 people inside WTC 2 at 8:46:30 a.m. New York City officially announced 2,749 fatalities at the WTC complex, including emergency responders, airplane passengers and crew (but not hijackers), and bystanders. NIST estimated that of the 17,400 ± 1,180 occupants inside WTC 1 and WTC 2 at 8:46:30 a.m., 2,163 to 2,180 perished. No information could be found for 17 persons. More than twice as many occupants were killed in WTC 1 as WTC 2, largely due to the fact that occupants in WTC 2 used the 16 minutes between the attacks on WTC 1 and WTC 2 to begin evacuating, including the use of elevators by some occupants in WTC 2.

The demographic characteristics of the evacuees was explored where the characteristics were relevant to the evacuation on September 11, 2001. Few differences in the characteristics of WTC 1 or WTC 2 were observed. Men outnumbered women roughly two to one. The average age was mid-forties. The mean length of employment at the WTC site was almost 6 years, while the median was 2 and 3 years for WTC 1 and 2, respectively. Sixteen percent of 2001 WTC evacuees were also present during the 1993 bombing, although many other occupants were also knowledgeable about the 1993 evacuation. Two-thirds of the occupants had participated in at least one fire drill during the 12 months immediately prior to September 11, 2001. Eighteen percent did not recall whether they had participated in a fire drill during that time period and 18 percent reported that they did not participate in a fire drill during that time period.

In WTC 1, all three stairwells and the elevators were destroyed in the impact region, extending as low as floor 92. No occupant evacuated from above the 91st floor, although some survived until the building collapsed after 102 minutes. Helicopter rescue from the roof was considered by an NYPD aviation unit, but deemed not possible due to the heat and smoke from the building fire. Occupants of both towers delayed initiating their evacuation after WTC 1 was hit. In WTC 1, the median time to initiate evacuation was 3 minutes for occupants from the ground floor to floor 76, and 5 minutes for occupants near the impact region (floors 77 to 91). Occupants observed various types of impact indicators throughout the building, including wall, partition, and ceiling damage and fire and smoke conditions. The most severe damage was observed near the impact region, fatally trapping some occupants. Announcements in WTC 1 were not heard by the occupants, despite repeated attempts from the lobby fire command station to order an evacuation. Damage to critical communications hardware prevented announcement

transmission. Evacuation rates reached a peak, steady-state in approximately 5 minutes, and remained roughly constant until the collapse of WTC 2, when the rate in WTC 1 slowed to about one-fifth of the peak, steady-state. WTC 1 collapsed at 10:28:22 a.m., resulting in approximately 1,500 occupant deaths, 107 of which were estimated to be below the 92nd floor.

The evacuation of WTC 2 was markedly different from the evacuation of WTC 1. There was a 16 minute period after WTC 1 was attacked, but before WTC 2 was attacked. During this time period, occupants were forced to decide whether to remain inside WTC 2, and if they decided to leave, they had to choose between using one of the three stairwells or using an elevator. Further complicating this decision process were multiple, conflicting announcements around 9:00 a.m., first instructing occupants to return to their offices, and then within one minute of impact, instructing them to begin an evacuation if conditions on their floor warranted that decision. Over 90 percent of WTC 2 survivors started to evacuate the building prior to its being attacked. Sixteen percent of the survivors used elevators to evacuate. Approximately 75 percent of the occupants who were above the 78th floor (the lowest floor of impact) descended to at least below the impact region prior to the attack on WTC 2. Over 40 percent of the survivors had left WTC 2 prior to 9:02:59 a.m. After WTC 2 was attacked, at least 18 individuals used Stairwell A, located in the northwest corner and furthest from the impact damage, to descend below the 78th floor to evacuate the building. Additional public address announcements were made after the airplane strike on WTC 2, although occupants who survived generally did not hear those announcements. After the initial peak in evacuation rate, the rate reached a steady-state similar to the rate observed in WTC 1 until approximately 20 minutes prior to collapse of WTC 2. The evacuation rate during the final 20 minutes dropped significantly, likely due to a decreased number of occupants remaining in the egress system below the 78th floor. NIST analysis indicated only 11 occupants initially below the 78th floor were killed when WTC 2 collapsed at 9:58:59 a.m. Overall, NIST estimated that 630 occupants of WTC 2 perished.

Using the statistical power of the telephone interview results, causal models were constructed to explain both evacuation initiation delay and average stairwell travel time per floor. The factors that best predicted evacuation initiation delay in WTC 1 were (1) which floor the respondent was on when WTC 1 was attacked, (2) whether occupants encountered environmental cues, and (3) seeking additional information (or milling) about the nature of the event. In WTC 2, the same process occurred as in WTC 1, except that perceived risk (sense of immediate danger) was a predictor of seeking additional information (along with floor and environmental cues). Analyses explored factors that affected time spent in the stairwells in WTC 1 exiting the building. The floor an occupant was on when WTC 1 was attacked (distance to safety) increased the probability of encountering an environmental cue (smoke, damage, fire, etc). Additionally, being on a higher floor predicted greater evacuation initiation delay times and encountering environmental cues, which predicted higher normalized stairwell travel time. Independently, interrupting evacuation for any reason increased the normalized stairwell travel time.

Constraints or aids to the evacuation progress were documented. Building announcements were cited by many in WTC 2 as a constraint to their evacuation, principally due to the 9:00 a.m. announcement instructing occupants to return to their work spaces. Crowdedness in the stairwells, firefighter counterflow, lack of instructions and information, as well as injured or disabled evacuees in the stairwells were the most frequently reported obstacles to evacuation. The most commonly mentioned forms of aid were assistance from coworkers and emergency responders and the photoluminescent markings in stairwells. Six percent of survivors in WTC 1 and WTC 2 reported a mobility challenge which slowed their evacuation. Sometimes the evacuation speed of others in the immediate area slowed down occupant

evacuation speed. Recent pre-existing injuries, medications, or medical treatments were the most commonly reported mobility challenges, while a small number used wheelchairs, were pregnant, or were elderly. A rest station for mobility-challenged occupants was established in WTC 1 somewhere between floors 12 and 20. Less than 10 minutes prior to the collapse of WTC 1, the occupants and helpers on the floor were ordered to evacuate, although it remains unclear whether all rest station residents survived.

Minutes prior to the collapse of WTC 2, an NYPD Emergency Services Unit (ESU) officer radioed from a floor in the 20s to the outside that he was having trouble ascending the stairwell due to the large number of occupants descending (Interview 24 NYPD [NIST 2004]). As only seven occupants who started evacuating below the impact region were known not to have survived, among several possibilities, a large group of occupants from above the impact floors may have identified the passable stairwell (Stairwell A) and may have been making their way out of the building as it collapsed.

Multiple evacuation models were used to simulate different WTC tower evacuations, subject to a number of assumptions. The goal of the modeling was to frame an understanding of actual evacuation findings on September 11, 2001. Simulations demonstrated that a phased evacuation (also known as defend-in-place, whereupon occupants on the fire floor and the immediately surrounding floors descend to three floors below the fire floor) would have taken between 4 minutes to complete (without delays in evacuation initiation) and 11 minutes to complete (with evacuation initiation delays between 0 and 10 minutes). Total evacuation of a tower assuming a full occupant load without visitors (19,800) would have required as few as 92 minutes to 112 minutes. With visitors (total population 25,500 people) total evacuation would have required as little as 114 minutes to 142 minutes. The ranges reflect two different model outputs, each assuming two different delay times (no delay and a 10 minute distribution of delay times). An evacuation simulation for 8,800 people (approximately the number present in each tower on September 11, 2001) in the absence of any damage to the building, would have required at least 52 minutes to 71 minutes, depending on the model or the delay times. Finally, the EXODUS model was ‘calibrated’ to approximate the gross evacuation rates observed in WTC 1 and WTC 2 on September 11, 2001. Once the model input necessary to approximate the observables was determined, additional occupants were added in order to estimate how many occupants might have been unable to evacuate on September 11, 2001 (given the damage to the building and observed delay times) if the buildings had had larger occupant loads. NIST estimated that approximately 14,000 occupants would have been unable to evacuate from WTC 1 and WTC 2 on September 11, 2001, had the starting building population been 19,800 in each building.

E.2 REFERENCE

NIST (National Institute of Standards and Technology). 2004. NIST WTC Emergency Responder Interview Data Set. Gaithersburg, MD.